The quantities $B_{0,2n+1}$, and, in fact, all the coefficients $B_{r,2n+1}$, can be studied algebraically from the relations (14). The algebraic solution of equations (15), together with a formal study of convergence, would be of great interest; meantime the numerical illustrations given in the foregoing discussion may serve to show the possibility of a general scheme which includes waves of any permissible height.

Experiments on the Effect of the Vibration of a Stretched Wire forming Part of a Closed Electric Circuit.

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In connection with some experiments involving the use of a thermo-microphone of small dimensions, I tried one of large proportions, to compare its efficiency with that of the small one. It consisted of a loop of silver gilt wire, 4 feet in length, stretched lightly between two glass insulators mounted on a stiff wooden batten. It was joined up in a circuit with a 10-volt battery and the primary winding of the step-up transformer of a three-valve (low frequency) amplifier, the secondary winding of the third valve of the amplifier leading to a pair of 60-ohm Brown telephones, which were used for recording the effects of sound vibrations on the loop of wire.

The listener at the telephones was situated in a quiet place some distance from the room in which this wire was fixed, and he could not hear with his naked ears the sounds produced to test the microphonic capabilities of the warmed wire. The response to these sounds in the telephones was well marked, the wire evidently acting as an efficient, though weak, microphone. Musical notes, produced by blowing organ pipes and a small syren, were loud and clear; laughing, whistling, and humming were easily differentiated, though speech was not intelligible.

The current flowing through the wire was $\frac{1}{4}$ ampère, and maintained its temperature slightly above that of the surrounding atmosphere. The voltage was then reduced in steps, and, though the intensity of the sound in the telephones also reduced, after a certain point, some sounds were still distinguishable after the battery had been disconnected and the circuit closed. The wire was now at the same temperature as that of the air.

Thus the microphonic effect cannot be altogether attributed to the temperature of the wire being maintained, by means of an electric current, above that of air.

This experiment is only mentioned in order to show the line of thought which started the experiments with various wires described briefly below, but it is typical of many of them.

The wires tested comprise the following:—

(*a*) Soft, bright iron wire, used in millinery, about 30 S.W.G. Resistance cold, 1 ohm per foot, increasing with a rise of temperature, decreasing when subject to tension. This proved very susceptible and responsive to vibration at first, but has little elasticity, and stretches easily; when it becomes fatigued, and is then inconsistent.

(*b*) Steel piano wire, 28 S.W.G. Resistance 0·9 ohm per foot, cold, increasing with heat or tension. Very consistent and responsive.

(*c*) Silver gilt, as used in embroidery, unwound from gimp and used in an open spiral of about twenty turns to an inch. Resistance, cold, averages 10 ohms per foot, depending on the pitch of the winding, increasing with heat or tension. Susceptible and fairly consistent, but difficult to manipulate. Is of flat section and about 32 S.W.G.

(*d*) Annealed soft iron, black, 22 S.W.G.; little used; not very susceptible.

(*e*) Pure silver, 0·125 ohm per foot; a small length only available; not very susceptible.

(*f*) High-conductivity copper wire, as supplied for winding and repairing coils, etc., in laboratory; 28 and 42 S.W.G. tried. Susceptible, but stretches easily and has little elasticity.

Wires *a*, *b*, *c* were used in the experiments generally, being more responsive and suitable than *d*, *e*, *f*, which were only tested to ascertain if they possessed the same qualities in respect to vibration as the others. This was found to be the case. Lengths of wire varying from 9″ to 220′ were tried; they were stretched in various formations and their tension varied, and, when in a portable form, they were tried in various positions and localities.

The preliminary trials showed that errors might easily creep in through microphonic contacts at the terminals, to which the ends of the stretched wires were taken, for convenience in making the electrical connections. These were entirely eliminated by the use of indiarubber tubing over the wires and taking the strain on indiarubber-covered studs or through ivory plates, the ends of the wires being then soldered to the slack insulated conducting wires leading to the amplifier. Plug connections were used for battery and other connections.

The amplifier was placed in such a position (when possible) as not to be

affected by the vibration or sound used for testing the wire. This precaution is necessary in such experiments, as this instrument has a tendency to act as a microphone, and its casing has a very distinct note of its own, which is easily produced by tapping or vibration.

The telephones of the amplifier were repeatedly replaced or supplemented by a carborundum crystal rectifier in circuit with a galvanometer, and some quantitative results obtained, but the combination is not stable enough to be of much use for measurements requiring precision, though useful in preliminary investigations.

It was found that the amplifier was not essential to the apparatus when good response was obtained, and it was frequently dispensed with, the ends of the wire under test being then joined direct to the terminals of a telephone, with or without a battery in the circuit, but preferably with a step up transformer 1 : 100. Errors due to the amplifier were thus entirely eliminated, but at the expense of the intensity of the sound received in the telephone, which was sometimes nil, though plainly audible when the amplifier was used. On frequent occasions the amplifier could not be used with any advantage owing to the roaring produced in the telephones by the inductive effect of the alternating current in the electric power mains in the locality. This effect at times drowned all other sounds in the telephones. Even when the circuits over which I had official control were disconnected, this effect was not entirely absent. Possibly it may have some bearing on the results obtained, but their high-pitched tone is easily recognised and not accepted as a sound vibration. Their inductive effect was not noticeable in the circuit without the amplifier.

Regarding the intensity of the sounds produced in the telephone by the vibration of these wires, it may as well be stated that it never reached that of an ordinary Hunnings microphone, with 8 volts, under similar conditions of reception, and seldom exceeded one-half of its intensity. Resonance plays an important part in the action of these stretched wires, but it is not essential in order to obtain an effect. The practical value of such wires, as microphones, at present seems small, that is, so far as commercial purposes are concerned.

The following is a brief description of some of the most effective experiments that I have carried out with stretched wires.

(1) *To Ascertain if the Effect was due to the Vibration of the Wire in the Earth's Magnetic Field.*—Two similar steel wires, each 10 feet long, were stretched, by means of a weight, one in the lines of the Earth's magnetic force, the other normal to them. They were in a complete circuit with the amplifier and no voltage was added to the circuit. The wire not under test

was slack, and not in resonance with the tight one under test. The tautened wire was plucked, softly tapped with the finger tips, and lightly bowed with a rough (insulated) wire, and very numerous trials with variations were made, but the difference in the intensity of the sounds in the telephones, with similar adjustments of the amplifier, was inappreciable; on a few occasions when everything was adjusted to get the minimum sound audible to the listener, the wire normal to the lines of magnetic force was very slightly more responsive. A lecture room monochord, similarly tested, gave no indications of any effect that can be attributed to the earth's magnetism, and a similar negative result has been obtained with all other portable apparatus that I have used in the experiments.

The effect, therefore, does not appear to be due to the presence of the earth's magnetic field, nor can I find any evidence from my experiments that it is due to the alternating field caused by the local electric power mains. Regarding the latter, the effect in the telephones with the amplifier was invariably better the less the inductive effect of the alternating field, under similar tests of apparatus.

(2) *Endurance Test.*—220 feet of (*a*) soft iron wire was stretched between two lamp posts and the ends brought into a window to the amplifier. The wire formed a triangle, 15 to 25 feet from the ground, of three unequal sides, 100, 70 and 50 feet respectively, the long side lying N.E. and S.W., and dipping 10 feet in this length.

On the first day factory and steamer whistles between E. and N.W. within 1 mile were easily heard in the telephone, sometimes quite clearly and sometimes as grating noises. Hammering in a ship-repairing yard was very audible. The addition of a 4-volt battery to the wire circuit had no appreciable effect. Inductive effects from the power mains varied greatly, the switching on or off of circuits having considerable effect. Plucking the wire just outside the window was very loudly produced in the telephone though inaudible to the person plucking it. The amplifier was then cut out of the circuit and the ends of the iron wire joined direct to a 60 ohm P.O. telephone. Plucking the wire was still plainly audible in the telephone, with or without a 4-volt battery in the circuit.

This span was left out for a week during wet squally weather in April, and again tested with the amplifier. The whistles were still audible but much fainter with similar adjustments, as was the effect from plucking the wire, and it broke when being lightly plucked and could not, therefore, be tested without the amplifier. It was much rusted and evidently had lost some of its response and it was not replaced for further trials.

(3) Open frames of light pine wood, 33 inches square, were wound diagonally

with about 50 feet of wire, zigzagged across adjacent sides, and comparisons made between (*a*), (*b*), and (*f*). (*a*) at first proved much the most susceptible, and (*f*) the least so; they required to be set up frequently owing to their stretching and gradually lost their power of response; (*b*) steel, though much slacker owing to the difficulty of tightening it on these light frames, was the most consistent in its response.

These frames were tried in various positions, *e.g.*, suspended in the middle of a room, resting on cushions and against a resonant background; they were also tried joined up in the circuit together in series and in parallel.

The best effect was obtained with a resonant background, and with (*a*) and (*b*) joined in series with 12 volts in the circuit. Musical notes sounded at a considerable distance from them, and tunes lightly whistled a few yards from them were very clearly heard in the telephones of the amplifier in a distant room. The ticking of a metronome at 6 feet distance was very distinct. With no voltage in the circuit the intensity of the sounds was decreased and the metronome was not audible.

(4) Grids were constructed of celluloid plates, 10 inches square, bent into the shape of a segment of a cylinder of large radius. Notches were cut on opposite sides, and the wire was wound through these and kept in tension by the spring of the celluloid, lengths of wire up to 10 feet, of 8 to 17 strings, were tried of (*a*) and (*c*). Similar results to those with the frames were obtained, and these shorter and more compact windings appeared to give better results than those on the frames, especially when the apparatus was, as a whole, in resonance with the note, very intense sounds being then obtained, but when not in resonance the sounds were weak and sometimes absent in the telephones; (*a*) iron wire gave the best results.

(5) Single or double wires of *all* types mentioned were stretched axially (or nearly so) in a closed organ pipe or tubular resonator, their tension being regulated by a weight, spring, or adjusting screw, with these the response to musical notes sounded outside but near these resonators was very slight, but was audible when in resonance with them.

Breathing lightly across the open end of a resonator, if properly adjusted to its fundamental note, produced a loud clear note in the telephone, though no sound of a note was audible to the blower; if the same person performed both functions the result was very striking; overtones produced by over-blowing were remarkably loud and clear, and blowing softly into the mouth of an organ pipe fitted with one of these wires (producing its fundamental note) caused the telephone to respond with an intensity that was almost deafening, if the amplifier was in the circuit. The tension of the wire in the tube has a great influence on the tone in the telephone, a few turns of the

adjusting screw changing the quality and intensity of the sound from a sharp clear note to a weak and uncertain one, or *vice versa.*

(6) Other simple arrangements of testing stretched single or multiple wires have been tried, and clear sounds have been heard in the telephones from syrens, whistles, hooters, etc., at distances exceeding one mile.

The steel piano wire has proved to be the most responsive and consistent to these distant sounds; the copper wire the least so.

In spite of the numerous tests carried out, it has not been found possible to draw any definite conclusions as to the effect of the tension of the wire, its length or its displacement, when vibrating, on the intensity of the sound produced in the telephone.

Much depends on the resonance of the mounting, *e.g.*, a short slack steel wire, which was really only the end of the wire under test, gave consistently the loudest sound, for a given slight displacement, of any tested, much louder than the remainder which was at high tension. The short portion was secured to a loose beading, the tight portion to a firm plank of the window frame, the insulation of the supports was perfect for both, and could not affect the result. The other end of the wire, fitted similarly, gave louder response when tight than when slack; it was, however, only half its length. Generally, the high pitched notes were the loudest, and responded to smaller vibrations than when tuned to a low pitch, and rapid forced vibrations of extremely small amplitude had more effect than those of large amplitude and low frequency, though the latter would, in the cases I mention, have imparted much greater energy to the wire than the former. The above applies to both the steel and the silver gilt (gimp) wire, the latter was at all times more responsive to slight rapid displacements than to large slow ones. It was peculiarly sensitive to longitudinal stroking, that is across its spiral windings, and less sensitive (in proportion to its general behaviour) to musical notes than to noises, unless the resonance was very good.

The addition of a low voltage battery to the circuit of the wire under test increases the intensity of the sound in the telephone, but if the voltage is above a certain point, depending on the wire, the clearness of the tone is apt to become blurred, and a rough grating noise added to the sound, similar to that experienced sometimes in an ordinary telephone circuit. With the short and medium length of wire usually tested, 5 volts was the critical voltage, 7 volts invariably proving to be too much with the steel and iron, though not always so with the silver gilt wire.

The limited time and appliances at my disposal may prevent me carrying out detailed research work in this matter.

There are many records in scientific publications of experimental work in

connection with the effect of torsion on the susceptibility of wires and rods to magnetisation, also on the thermo-electric effect of stretching parts of wires in a circuit, but I have not found many references that bear directly on these experiments. However, I find the following references in 'A History of the Theory of Elasticity and of the Strength of Materials,' by Todhunter and Pearson, 1893:—

Vol. 2, Art. 705, Matteucci.—Stretching a wire in the axis of two coils, one used for magnetising it and the other for recording induced currents in it, showed an induced current in the latter; after opening the circuit, the effect increased.

Vol. 1, Art. 1248, W. Sullivan.*—Contains some experimental evidence of the vibrations of wires and rods producing electric currents in them, etc.

Art. 1333.—De la Rive communicated to the Royal Society that all conductors when placed under the influence of a strong electromagnet gave a very pronounced sound on the passage of a current. This may be taken as the inverse effect of my experiments.

In a footnote at the bottom of the next page (720), it is stated that Marrian had suggested that a mechanical vibration or note would produce electricity.

My experiments seem to have confirmed this suggestion to have been correct, thanks to the advent of more delicate apparatus for the detection of currents with a frequency of sound waves, which was non-existent in his days.

[*Note added on July 9th*, 1918.—Platinum, tungsten, aluminium, brass and manganin wires, a steel rod, 3/16 inch in diameter, and a brass tube, 1 inch in diameter, have also been tested and have given similar results to those described.

This vibratory effect can also be demonstrated by its inductive action on a neighbouring circuit; as a ring of homogeneous metal can be used as the vibrating body, all sources of error from the junctions of the electrical circuit are thereby eliminated.]

* 'Phil. Mag.,' vol. 27 (1845).